Analysis of the Shortwave Cloud Forcing and Surface Shortwave Flux in the Meteorological and Oceanographic (METOC) Modeling and Prediction Systems

Duane E. Waliser
Institute for Terrestrial and Planetary Atmospheres
State University of New York, Stony Brook, N.Y., 11794-5000
516-632-8647; wailser@terra.msrc.sunysb.edu ; http://terra.msrc.sunysb.edu/onr

Award N000149710527; Start Date: 4/1/97

LONG TERM GOALS

The United States Navy is the Department of Defense's main source for standard meteorological and oceanographic (METOC) predictions. At the heart of these predictions are the short-to-medium range weather forecasts produced by the Navy Operational Global Atmospheric Prediction System (NOGAPS; Hogan and Rosmond, 1991). Surface flux fields from NOGAPS forecasts are used as input to the oceanographic prediction systems. These systems include: 1) the Thermodynamic Ocean Prediction System, 2) the Polar Ice Prediction System, and 3) the Third Generation Wave Model. Given the prominent role surface fluxes play in these systems, it is clear that their proper simulation by NOGAPS is vital. Presently, there are significant shortcomings in the NOGAPS simulation of the net surface shortwave flux (long-term mean biases greater than 50 Wm^{-2} in many tropical/subtropical areas), as well as other surface heat flux components (similar size biases in the latent and net surface heat fluxes). The long term goal of this research is to determine the underlying causes for these shortcomings and help implement modifications for improvement in order to: 1) enhance this model's physical representation of the atmosphere and extend the skill of its medium range weather predictions, and 2) improve the skill of the oceanographic and coupled prediction systems via the improved simulation and prediction of the surface energy budget.

OBJECTIVES

The objectives of this research are to analyze and improve the model representations of the surface shortwave flux and the associated radiative-convective processes. Meeting these objectives includes the following: 1) Compare and analyze observed and NOGAPS-modeled cloud characteristics, rainfall, precipitable water, surface latent heat flux, and top of the atmosphere (TOA) and surface radiative fluxes to help identify the parameterizations which underlie the biases evident in the modeled surface shortwave; 2) Use observed data sets in conjunction with single-column models to further diagnose the shortcomings in the physical paramerizations and to help focus model development efforts; and 3) In conjunction with the NOGAPS modeling team, develop model parameterization improvements based on the above analyses, and then test, and possibly implement, these improvements in the global forecast model.

APPROACH

The approach taken in this study can be broken down into the following three parts:

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE **Analysis of the Shortwave Cloud Forcing and Surface Shortwave Flux in the Meteorological and Oceanographic (METOC) Modeling and Prediction Systems**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **State University of New York,Institute for Terrestrial and Planetary Atmospheres,Stony Brook,NY,11794-5000**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

1) Assemble satellite-based and ground-based verification data sets and repackage them into a data format that will facilitate comparison with NOGAPS simulation output. These data sets include the ERBE products, ISCCP cloud products, MSU precipitation, SSM/I precipitable water, ship-based surface heat flux climatologies, as well as satellite surface shortwave data sets. Assemble the necessary output parameters from the most recent NOGAPS climate simulation and repackage into a data format that will facilitate the analysis. Begin by performing the analysis/comparison on the climatologies of the NOGAPS output and the available observations. At a later date, focus on the simulation of interannual variability.
2) Using buoy-observed values of surface shortwave flux and a single-column version of the NOGAPS radiation code, validate the modeled clear-sky surface solar radiation flux values. This comparison will further help to isolate the causes of the shortwave flux biases. The principle reason for focusing on the clear-sky values is that the (large) uncertainty in specifying the observed cloud amount is removed, and thus the results from the comparisons are easily interpreted. One of the main steps in accomplishing this task is to filter out cloudy periods from the buoy-observed records of shortwave flux.
3) From the two types of model-observation comparisons described above, and in collaboration with the NOGAPS modeling team, determine the underlying causes for these parameterization deficiencies, suggest improvements in the model formulations, and re-analyze the new simulations based on the improved physical parameterizations. In addition, use a single-column model (SCM) of NOGAPS (if/when it becomes available) containing all the physical processes (i.e. radiation, convection, etc.), along with the SCM forcing and validation fields from experiments such as COARE, ARM and GATE, to facilitate the diagnosis and improvement of the model physics.

WORK COMPLETED

Nearly all of the tasks associated with Part 1) above (all but the interannual variability assessment), and most of the tasks associated with Part 2) above, have been completed during the first 18 months of the award period. In addition, some efforts have been undertaken associated with Part 3) as well. This puts the project on or ahead of schedule relative to the proposed time table for the project.

With respect to Part 1) of the APPROACH, all surface and TOA data sets required for the project have been acquired and re-formatted for the purpose of the analysis. Dr. Hogan (NRL) has run a 15-year simulation of the NOGAPS model (Version 3.4) for the analysis and provided the output to the PI. Long-term mean model-data comparisons have been carried out at both the surface and the TOA to identify the underlying causes of the shortwave biases in NOGAPS model (see RESULTS).

With respect to the Part 2), a number of surface buoy-observed shortwave data sets have been collected. These include a number of records obtained from Robert Weller (Woods Hole Oceanographic Institution) from regions such as the subtropical Atlantic (Subduction Experiment), the Arabian Sea, western Pacific (TOGA COARE), etc. In addition, the available surface shortwave data from the TOGA TAO moored array in the tropical Pacific has also been obtained. These data are being collected to provide for better validation of model-derived shortwave values, either for direct comparison, or for indirect comparison via their use in validating satellite retrievals of surface shortwave which can then be used to compare against global model fields. At present, we have developed a method to filter out cloudy periods from the buoy shortwave records (Waliser et al. 1998a) using International Satellite Cloud Climatology Project (ISCCP) DX data and a four-step cloud-screening procedure. This method has been applied to the buoy records from the Subduction Experiment (funded

by ONR grant N00014-90-J1490; PI: R. Weller), with the clear-sky values then used to compare against NOGAPS model-derived values (see RESULTS).

With respect to Part 3), preliminary collaboration with Dr. James Ridout at NRL has resulted in the analysis of a number of convection parameterization sensitivity tests in the global model to try and correct the shortcomings believed to exist in the NOGAPS convective/cloud parameterizations. As yet the planned development of the single-column model of NOGAPS by NRL staff with the complete set of physical parameterizations has yet to be completed.

RESULTS

The results pertaining to Part 1) have been "published" on the web (see web address in REFERENCES), presented to the Global Modeling Division at NRL, and have been written up in a manuscript for submission (Waliser, D. E., and T. R. Hogan, 1998: Analysis Of Surface Heat Fluxes in a NOGAPS Climate Simulation: Influences from Convection, Clouds And Dynamical Processes. To be Submitted to *J. Geoph. Res. - Atmosphere*). Briefly, the results from the climate simulation indicate that the NOGAPS model under predicts the net surface shortwave flux by about 30-50 Wm^{-2} in much of the subtropical oceans and over predicts the net shortwave flux in the western Pacific warm-pool and the midlatitude oceans by about 30-50 Wm^{-2}. In addition, NOGAPS over predicts the latent heat flux by about 40-60 Wm^{-2} in much of the subtropics and under predicts the latent heat flux over the northern ocean western boundary currents by about 30-50 Wm^{-2}. These biases combine to produce significant errors in the surface net heat flux, with too little heat entering the subtropical/tropical oceans (~ 50-70 Wm^{-2}) and too much heat loss in the midlatitudes (~50-70 Wm^{-2}). Examination of related quantities indicates that these biases are mainly coupled to shortcomings in the convective cloud and/or boundary layer parameterizations (as opposed to being purely associated with a problem with the radiation parameterization) which leads to the premature release of moist static energy from the boundary layer in regions just outside the deep convective zones. This leads to enhanced cloudiness, rainfall, and surface evaporation, as well as to a reduction in the surface shortwave flux and outgoing longwave radiation, in the subtropical regions. Furthermore, due to the early release of the moist static energy, there is a reduction in clouds, rainfall and water vapor content, as well as enhanced surface shortwave flux and outgoing longwave radiation, in the deep convective zones. The reduction in rainfall reduces the strength of the large-scale circulation (e.g., Hadley and Walker circulations), which in turn reduces the strength of the subsidence in the subtropical regions that is in part supposed to suppress the convection processes in these regions. The implications of these results are discussed further in the manuscript in terms of the coupling between surface fluxes, convection, clouds and the dynamical processes, as well as their impact on the organization of transient systems. A remaining goal of Part 1) is to determine the operational forecast lead-time when the biases in the NOGAPS modeled climate become influential and/or detrimental.

Most of the results pertaining to Part 2) have been incorporated into Waliser et al. (1998a). This manuscript describes the method developed to filter out cloudy samples from buoy-observed shortwave records and then demonstrates how the resulting clear-sky values can be used to help validate radiation parameterizations from a numerical model. At present, the validation has been done for both the National Center for Atmospheric Research Community Climate Model (Version 3) and for NOGAPS. The figure below shows the results for the NOGAPS comparison. In general, the comparisons show that the NOGAPS radiation parameterization appears to be doing well at simulating clear-sky shortwave radiation, at least for this particular region (i.e. subtropical north Atlantic), with mean biases typically less than 1% of the total flux. However, some caution has to be taken in interpreting this figure. The

single-column radiation model was written only to provide net surface shortwave radiation, while the buoys measure downwelling radiation only. Thus, the comparisons required a conversion of either the observed or modeled value. In this case, the buoy values were converted to net surface shortwave flux using the clear-sky albedo model of Briegleb et al. (1986). This conversion may account for what appears to be a model underestimate (overestimate) at high (low) sun elevations. In the future, it is hoped these comparisons can be done in a more robust manner using a version of the SCM model that supplies downwelling radiation in addition to the net radiation. As is, the results support the findings above which suggest that the shortcomings found in the comparisons between model and observed values of surface shortwave are likely to be more significantly associated with shortcomings in the parameterization of clouds/ convection, rather than the radiation itself. The methodology and clear-sky data sets produced from this portion of the project will continue to be used to validate the parameterization in other regions as well as to validate future modifications to the parameterization. Such improvements are still warranted as the present version of the radiation code does not include some trace gases or aerosols (personal communication: Harshvardhan, Purdue). Inclusion of these processes would decrease the downwelling shortwave radiation at the surface from its present values. In this context, the comparisons for the net surface shortwave flux show relatively good agreement because the NOGAPS surface albedo over the ocean has been tuned upward (0.09; observed is about 0.06) to account for these missing processes.

The analysis pertaining to Part 3) of the APPROACH are still in a preliminary stage. The results to date consist of a number of convective parameterization sensitivity tests carried out by James Ridout at NRL and then analyzed at SUNY. While a number of cases show noteworthy improvements (see web address in REFERENCES), the accountability and operational nature of the NOGAPS model dictates that significant testing be undertaken to ensure that in addition to possible improvements obtained by a given change in a parameterization, that no other aspects of the model predictive skill suffer (e.g., tropical cyclones, frontal systems, etc.). This aspect of the project is still in progress.

IMPACT

The main impact of the above results has been to draw together a set of fairly wide ranging set of biases of the NOGAPS model climate (shortwave, evaporation, rainfall, circulation strength, etc.) and indicate the likely model process underlying these biases, namely moist convection. In doing so, this helps to focus model development on the model parameterizations that are most responsible, i.e. moist convection and possibly boundary layer parameterizations. Ongoing and future efforts will utilize these results to improve these parameterizations in order to: 1) enhance this model’s physical representation of the atmosphere and extend the skill of its weather predictions, and 2) improve the skill of the oceanographic predictions via the improved simulation and prediction of the surface energy budget.

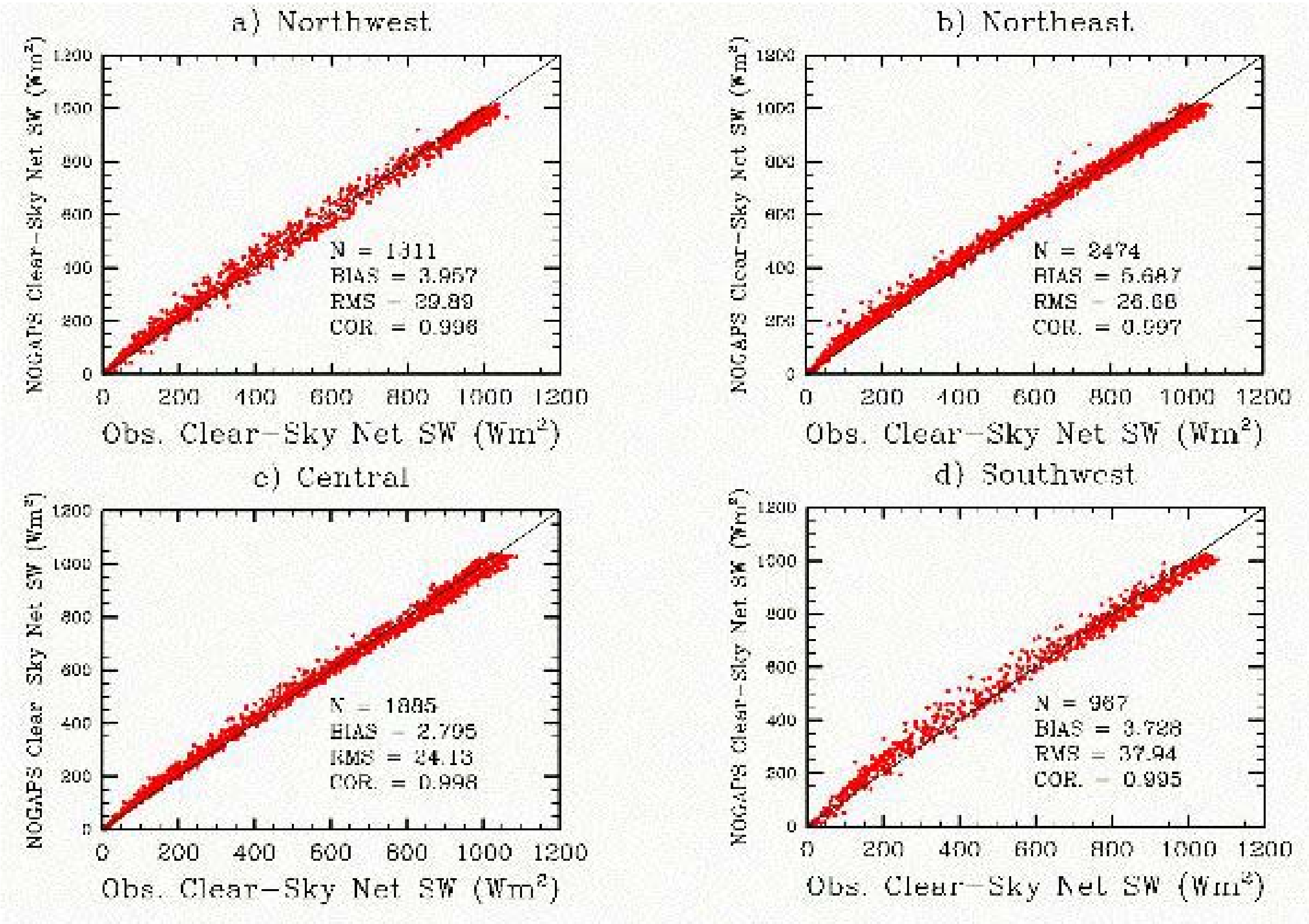

Figure 1. Scatter plots of observed (x-axis) and NOGAPS modeled (y-axis) clear-sky surface net shortwave values at each buoy location. The observed values are 15-minute averages. The surface albedo parameterization of Briegleb et al. (1986) was used to convert the observations of downwelling surface shortwave to net surface shortwave. The clear-sky samples come from the period June 1991 to June 1993. The locations of the as Northwest, Northeast, Southwest, and Central buoys were: 33°N, 34°W; 33°N, 22°W; 18°N, 34°W; and 25.5°N and 29°W.

TRANSITIONS

The transition of results of this work will occur via the collaboration between the PI and the Global Atmospheric Modeling Division at NRL. The intention is to take what is learned to identify specific parameterizations that can improved, implement and test improvements in conjunction with the NOGAPS modeling team (see APPROACH and WORK COMPLETED), and then transition these improvements into the operational forecast system.

RELATED PROJECTS

The PI has also informally investigated the simulation quality of the Madden-Julian Oscillation (MJO) in the NOGAPS model. This intraseasonal phenomena has significant influence on tropical rainfall variability and the onset and breaks of the Asian-Australian monsoons, as well as modest influence on long-range mid-latitude weather forecasts. Dr. Hogan (NRL) has supplied daily output for

a number of variables from the same simulation described above in order to assess the simulation of this process. Preliminary study indicates the NOGAPS model performs poorly with respect to the simulation of this phenomena. In conjunction with this effort, a statistical model for extended-range tropical rainfall has been developed using outgoing longwave radiation (OLR) in an effort to provide a benchmark for the skill of long-range predictions of the MJO (Waliser et al. 1998b). This portion of the NOGAPS research overlaps with the PI's National Science Foundation study on The Nature and Predictability of the Madden-Julian Oscillation in the Coupled Ocean-Atmosphere System. This NSF study is exploring the effects of ocean coupling on the simulation and prediction of the MJO. Results thus far indicate that even simplified sea surface temperature coupling via a slab mixed-layer can significantly improve the quality of a general circulation model's simulation of the MJO (Waliser et al. 1998).

As part of a NASA funded study, the PI is currently gathering all available, high-quality buoy-observed records of surface shortwave (about 8000 days worth, including data in the Atlantic, Pacific and Indian Oceans) in order to meet the following objectives: 1) perform quality control on the data, 2) compute associated clear-sky and shortwave cloud forcing time series for each buoy using a validated numerical radiation code, 3) package the data into a format that can be readily distributed to the satellite and model development communities, and 4) use the data to make a comprehensive assessment of the quality of satellite retrievals of surface shortwave over the ocean where up to the present very little validation has been undertaken.

REFERENCES

Briegleb, B. P., P. Minnis, V. Ramanathan, E. Harrison, 1986: Comparison of Regional Clear-Sky Albedos Inferred from Satellite Observations and Model Computations, J. Clim. Appl. Met., 25, 214-226.

Hogan, T. F., and T. E. Rosmond, 1991: The Description of the Navy Operational Global Atmospheric Prediction System's Spectral Forecast Model. Mon. Wea. Rev., 119, 1786-1815.

Waliser, D. E., W. K. Lau, J. H. Kim, 1998: The Influence of Coupled Sea Surface Temperatures on the Madden Julian Oscillation: A Model Perturbation Experiment. J. Atmos. Sci., In Press.

World Wide Web Address: http://terra.msrc.sunysb.edu/onr

PUBLICATIONS

Waliser, D. E., R. A. Weller, R. D. Cess, 1998a: Comparisons Between Buoy-Observed, Satellite-Derived and Modeled Surface Shortwave Flux over the Subtropical North Atlantic During the Subduction Experiment. J. Geophys. Res., Submitted.

Waliser, D. E., C. Jones, J. K. Schemm and N. E. Graham, 1998b: A Statistical Extended-Range Tropical Forecast Model Based on the Slow Evolution of the Madden-Julian Oscillation. J. of Climate, In Press.

IN-HOUSE /OUT-OF-HOUSE RATIOS

While Drs. Hogan and Ridout from NRL have collaborated on the above work, the funding for the award has been disbursed 100% out-of-house to the State University of New York at Stony Brook.